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Non-Indigenous Marine Species (NIMS) in Biofouling on RAN Vessels: Threat Analysis

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ABSTRACT

The translocation of marine species by anthropogenic vectors, such as ships' ballast water, hull fouling, and fouling in sea chests and internal seawater systems, poses a biosecurity issue by enabling the colonisation and establishment of species in regions beyond their native range. To gain understanding of the biosecurity risk posed by biofouling from RAN vessels returning from overseas DST Group conducted a survey of hull biofouling, with *URS Australasia* sampling 26 RAN vessels, which involved 53 inspections over the period 2001 – 2010, including at least one representative from all commissioned classes. Also, DST Group conducted port surveys of four defence-restricted ports where RAN vessels from this survey were berthed to determine if there was any increased biosecurity threat due to differences in RAN operational aspects compared to non-defence vessels. The areas of operation visited by RAN vessels in this survey were assessed to determine which region posed the highest biosecurity threat to Australian waters. In total, the hull biofouling survey identified over 260 different taxa of macroalgae and macroinvertebrates and vertebrates. Twenty-one of the taxa identified have been previously reported as invasive marine pests overseas and are therefore considered potentially invasive in Australian waters. This subset of twenty-one species will be looked at in depth in this report to determine the potential biosecurity threat they pose to Australia.

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Executive Summary

The Royal Australian Navy (RAN) has recognized that its fleet, like other sea-going vessels, remains susceptible to biofouling in niche areas on hulls and in sea chests and internal pipe work, regardless of well-maintained antifouling coatings and can have detrimental operational and biosecurity ramifications. While hull niche areas on RAN vessels are largely analogous to those on various commercial vessels, RAN operational profiles differ and consequently warships may pose a different risk with respect to introductions of non-indigenous marine species (NIMS).

A survey to determine the biosecurity risk posed by RAN vessels was carried out by sampling and identifying biofouling on hulls and within niches on 26 individual RAN vessels and submarines between 2001 and 2010, with the majority of vessels sampled during 2003 and 2008. The survey identified over 260 different taxa. Most were categorised as either endemic, cosmopolitan or cryptogenic (origin unknown) species, and posed no bio-security risk to Australian waters. However, several species were identified as a “first introduction” to Australian waters having not previously been recorded in Australia, and may pose a biosecurity risk, and it is this subset of species that will be assessed in this report.

The three regions of deployment of RAN vessels, in this survey ; South East (SE) Asia, the Middle East Area of Operations (MEAO) and the Pacific Region were assessed and it was determined that SE Asia posed the highest biosecurity threat to Australia, predominately to the northern Australian coastline. Tropical species, particularly from the SE Asia region, were identified on vessels berthed at temperate ports in Australia, and in many cases these species persisted on vessels moored for several months. Most tropical species are relatively dormant in temperate regions however once these infested vessels travel into tropical climes, these species become "activated" where they pose a biosecurity threat. Prior to deployment from temperate ports to tropical regions along the northern Australian coastline, vessels need to be assessed to ensure tropical species are not present.

RAN operational **manoeuvres** such as long-term offshore mooring, and slow-water patrolling were evaluated for vessels in the MEAO, where several biofouling incidents had resulted in operational failure and required in-field maintenance because of fouled internal pipe systems. Despite these incidents, long trans-oceanic journeys back to Australia and the associated high sheer-rates and variable salinity and temperature gradients increased mortality rates for more susceptible species. This caused a reduction in the number of species surviving in hull fouling, reducing the biosecurity threat posed by RAN vessels returning from this region.

While the main focus of this survey was the biosecurity threat posed from hull biofouling present on vessels arriving from overseas, domestic-operations RAN vessels predominately from the northern Australian coastline were also assessed. These RAN vessels were based at Trinity Inlet in Cairns operating in and around the "top-end" of Australia and recorded the largest number of NIMS in hull biofouling in this survey. This has implications for both defence and non-defence vessels. Domestic vessel movements are not as closely regulated allowing vessels greater ease to unknowingly translocate species from infected to pristine regions. A concerted effort and increased vigilance by all parties concerned is required to better regulate range expansion by NIMS already present in Australian waters.

Also, one of the Trinity Inlet vessels provided an example of reverse translocation, where a local species from the Cairns area survived a trip to and from an overseas destination. While this species is not regarded as a biosecurity threat overseas, this highlights the affinity and ease with which certain species are able to travel in biofouling and survive long voyages.

Also surveyed were four defence-restricted ports associated with the RAN vessels in this survey. They were: HMAS *Cairns;* HMAS *Kuttabul*; HMAS *Leeuwin*; and HMAS *Stirling*. The first three ports are contiguous with the coastline providing no barrier to the spread of NIMS translocated by either a defence or non-defence vessel, making it difficult to determine whether the biosecurity threat posed by RAN vessels is any greater or less than from non-defence vessels in these areas. However, HMAS *Stirling* is located on Garden Island in Western Australia (WA) and is isolated from the mainland. Surveys of this port carried out by DST Group identified a previously unknown caprellid *(Caprella californica)* directly attributable to HMAS *Stirling* via translocations by RAN vessels. Subsequent port surveys have recorded very substantial increases in numbers over the last several years, with the result that HMAS *Stirling* now serves as an inoculation point for *C. californica,* for vessels berthing in this port. Currently, there is little information of the effects C. *californica* on Australian marine biodiversity so it is difficult to determine the biosecurity threat. It is suggested that vessels deployed from HMAS *Stirling* undertake precautions such as pre-deployment cleaning and limit unnecessary visits to environmentally sensitive temperate and sub-tropical areas until the threat posed by this species is better understood.

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Luciana Montelli has completed a BSc (Hons) in Marine Biology at the University of Melbourne and is a member of the Environmental Signatures group at DST Group Melbourne. Currently Luciana is involved in a project to identify marine biota found in biofouling on the hulls of RAN vessels, as well as conducting port surveys at Garden Island, Western Australia and Trinity Inlet, Queensland to identify invasive marine pests. Luciana is also examining fouling patterns associated with niche areas on ships to determine whether there are any areas of high vulnerability with a pattern to biofouling.

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Contents

1. Introduction

Non-indigenous marine species (NIMS) are known to cause adverse environmental, economic, human health and social impacts (Burgiel & Muir, 2010; Bax & Carlton, 2011), and attempted eradication and/or management of potentially harmful NIMS following introduction and establishment is usually costly and rarely successful. One example, the incursion of the Black Striped Mussel, *Mytilopsis sallei,* into Darwin marinas in 1999 led to the closure of three marinas, and required vessel treatment and chemical dosing of marina waters at a total cost in excess of $2 million (Ferguson, 2000; Willan, 2000). Any new introduction is of concern and may pose a potential threat.

The Royal Australian Navy (RAN) maintains a fleet of over 50 vessels and submarines and one issue is the build-up of biofouling on hulls and in niches. The detrimental effects of hull biofouling on the operational and combat capabilities of ships and submarines are well documented (Schultz et al., 2010). However, recognition of the significant role of hull biofouling in the translocation of marine organisms is comparatively recent (Carlton, 2001). Nationally, RAN vessels operate throughout the Exclusive Economic Zones (EEZ) on a range of tasks, including border protection, search and rescue, hydrographic survey, general ship transit, and training activities. The principal areas of overseas operation by RAN vessels in this survey included; the Middle East Areas of Operations (MEAO), the Indo-West Pacific including SE Asia and the Western Pacific region, with certain regions identified as posing a high risk of infestation by invasive species. Translocation of NIMS by RAN vessels from any of these regions poses a potential risk to Australia's marine biodiversity and reflects negatively on the reputation of the RAN.

One example, the recent introduction of the Caribbean tubeworm (*Hydroides sanctaecrucis)* in the Port of Cairns, previously thought to be unrecorded in Australia at the time of the survey and now established in Australian waters, raised concerns. The appearance of this species in Cairns coincided with the presence of biofouled RAN warships, leading to unfounded accusations that HMAS *Brunei* and HMAS *Labuan* were responsible for the introduction of *H. sanctaecrucis* into Trinity Inlet. While this was unfounded and the initial incursion was traced back to the Indonesian tall ship Dewa Ruci (CRC, 2005; Hilliard, et al., 2005; Lewis et al., 2006), the public perception linking RAN vessels to the introduction of new marine pests generated negative public attitudes which adversely affect the public reputation of both the RAN and Defence as a whole (Gollasch, 2002). For this reason a survey was conducted on hull biofouling from RAN vessels to determine the biosecurity risk posed in an attempt to better understand the likelihood of translocation and introduction of NIMS to Australian waters by navy vessels, and the potential for deleterious impact on the environment from NIMS associated with navy vessel hull biofouling (Tzankova, 2009).

The RAN commissioned DST Group and URS Australasia to undertake a survey of biofouling assemblages on a representative selection of navy vessels and several Defence-restricted ports. The surveys aimed to identify and characterise the composition of vessel biofouling assemblages, identify vessel specific niche areas prone to biofouling, and understand operational requirements particular to navy vessels which have the potential

to make them more susceptible to infestation from NIMS than non-defence vessels. This information can then be used in the development of mitigation measures and biofouling management strategies to be implemented by RAN.

The taxonomic identifications of the biota in hull biofouling highlighted a subset of species which were potential high biosecurity risk species, and these are discussed in this report. The objective was to inform the RAN of the presence of NIMS which despite not being listed on the CCIMPE (Consultative Committee on Introduced Marine Pest Emergencies) Trigger List (Appendix A), the D.o.A. (Department of Agriculture) Target Species List (Appendix B), not previously recorded in Australian waters or with limited distributions in Australia, are known nuisance species overseas. Though none of the species identified on navy vessels in this report are named on either list, this does not necessary indicate they are benign.

2. Method

2.1 Collection

The biofouling survey consisted of a total of 32 in-water dive surveys, undertaken on 26 individual RAN ships and submarines, including 10 different ship classes, between October 2001 and June 2008. Survey sampling was carried out during in-water hull inspections as soon as practicable following the vessels' return from interstate or overseas deployment, with fouling-prone areas given priority when sampling for biota (URS, 2006). Several follow-up dry dock inspections were also performed. In preparation for each dive, the hull of each ship was assessed to determine niche areas most prone to fouling (URS, 2006). These included sea chests, intakes, anodes, dry dock support strips, rudder posts and hinges, shaft A-brackets, rope guards and stern tubes, uncoated log probes, non-antifouled sonar domes, non-antifouled propellers and bosses, other voids and appendages such as auxiliary propulsion units (APU's) (Figure 1.). Video transects over the entire hull length, as well as still-photography of biofouling found on the hulls were taken (Figure 1), along with sample collections of representative patches of biofouling found at a set of pre-identified sites and opportunistic locations (URS, 2006).

Survey dives took place at Fleet Base West (FBW) located at Garden Island Cockburn Sound, and HMAS *Leeuwin* located in the port of Fremantle, in Western Australia, HMAS *Kuttabul* located at Balls Head Bay, Sydney Harbour which forms a part of Fleet Base East (FBE) located in NSW and HMAS *Cairns* located at Trinity Inlet in Cairns, North Queensland. Only one sampling was conducted outside Australia in Dunedin, New Zealand.

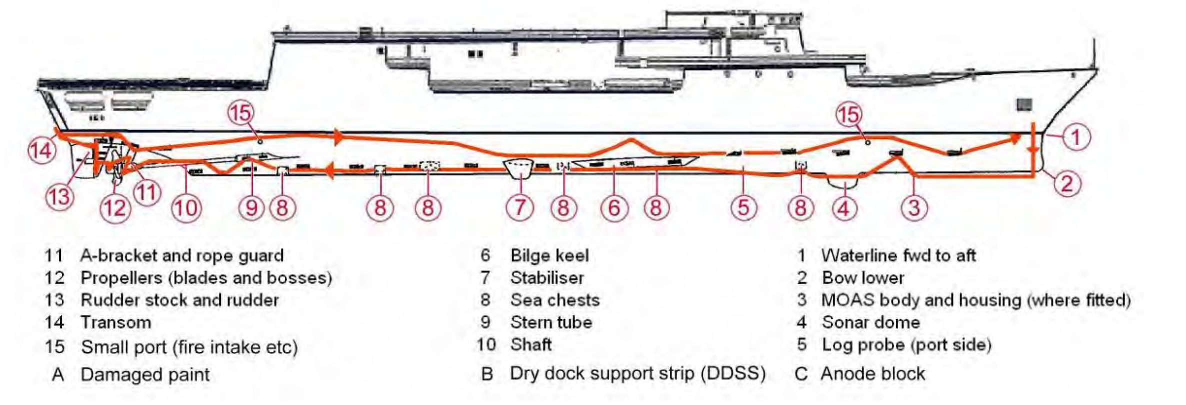

Figure 1. A listing of survey inspection and sampling locations for Anzac class vessel in survey (URS, 2006).

2.2 Sample Preservation and Taxonomic Identification

After collection, biofouling samples were preserved in ethanol and shipped to DST Group, Melbourne for sorting and identification. In the laboratory, the samples were first filtered to remove excess ethanol using filter paper in a Buchner funnel. The filtrate was then transferred to a plastic petri dish containing 20-30 ml of 10% glycerol and 90% ethanol solution. Samples were sorted under a dissecting microscope, into broad taxonomic groups, and then to species level.

The majority of species were identified at DST Group, Melbourne. If this was not possible, specimens were sent to relevant taxonomic experts (listed in *Appendix D).* Additional information regarding the distribution of NIMS was obtained from the World Register of Marine Species (WORMS, 2012)

2.3 Port Surveys

Several port surveys were carried out at Defence-restricted ports over the period of 2001-2010, and included: HMAS Sterling (FBW, WA); HMAS Kuttabul (FBE, NSW); HMAS Cairns (QLD).

2.4 Vessel Classes Surveyed

2.4.1 Submarines (SSG)

There were four Collins class submarines sampled between 2001 and 2004. HMAS *Sheean* was surveyed three times, HMAS *Dechaineux* twice, and HMAS *Rankin* and HMAS *Waller* once. Surveys consisted of both in-water and drydock examinations. The hull coating systems consisted of both the TBT-based *Intersmooth* and the fouling release *Intersleek* paints with a TBT-free paint *Ecoloflex* applied to HMAS *Waller*.

2.4.2 Anzac Class Frigates (FFH)

Four FFHs were sampled in particular HMAS *Anzac* which suffered severe mussel fouling while on duties in the MEAO. Two FFHs had a TBT-based coating the other two were copper-based.

2.4.3 Guided Missile Frigates (FFG)

Five FFGs were sampled including two vessels (HMAS *Sydney* (Aug 2003) and HMAS *Darwin* (May 2003)) which suffered severe mussel fouling while on duties in the MEAO. All FFGs had TBT-based coating systems.

2.4.4 Landing Platforms Amphibious (LPA)

One LPA was sampled at FBE. LPAs are used to carry out shallow inshore operations and consequently have a flat and almost featureless underside. The LPAs are subject to heavy wear and tear of the coating system on the bow stem and lower bow. The coating system used was *Intersmooth*.

2.4.5 Landing Craft Heavy (LCH)

Two LCHs were sampled at HMAS *Cairns*, with both undertaking domestic maneuvers. There was heavily damaged paint along the bow and underside of the vessels, a common occurrence for LCHs as a result of regular beach landings. One of the LCHs had travelled to the Pacific region. The coating system consisted of a TBT-based paint.

2.4.6 Auxiliary Oiler (AO)

One AO was sampled at FBW, after over 70 days alongside. The hull of an AO is essentially the same as those of commercial product tankers. At the time of the first inspection the vessel had spent 72 days alongside at HMAS *Stirling*. The coating system consisted of *Intersmooth, Intergard* and *Intertuf.*

2.4.7 Minehunter (MHC)

One MHC was sampled at HMAS *Waterhen*. The hulls of MHCs are unique, possessing three APUs, both forward and mid-ships log probes and also a variable depth sonar housed in a hull void. The coating system consisted of TBT-based paint.

2.4.8 Fremantle Class Patrol Boat (FCPB)

Two FCPBs were sampled at HMAS *Cairns*. Prior to this survey eight ‘suspect’ bivalves had been found and removed prior to undertaking general patrol duties, which were subsequently identified as common goose barnacles by DST Group. Both vessels remained in domestic waters. The coating system consisted of TBT-based paint.

2.4.9 Hydrographic Ship (HS)

One HS was sampled at HMAS *Cairns*, with its coating system in good condition. This vessel remained within domestic waters. The coating system consisted of TBT-based paint.

2.4.10 Survey Motor Launches (SML)

Two SMLs were sampled at HMAS *Cairns*. SMLs have catamaran hulls, generally with smooth lines and relatively few niches. Both vessels travelled domestically, and the coating system consisted of a copper-based paint.

3. Results

Table 1. Species identified from RAN vessels and status in Australian waters

Species	RAN Vessel(s) HMAS:	Status of species in Australia at Time of Survey 2001-8
Amphibalanus zhujiangensis	*Darwin* (Dec 2003); *Dechaineux* (Aug 2003)	Concurrent introduction at Eden (NSW) 2003.
Balanus pulchellus	*Dechaineux* (Aug 2003); *Wewak* (May 2004)	Not recorded
Branchioma bairdi	*Brunei* (May 2004); *Melville* (May 2004); *Wewak* (May 2004)	Not recorded
Cancellaria sp.	*Sheean* (Dec 2003)	Not known
Caprella californica	*Anzac* (Jul 2003); *Hawkesbury* (Nov 2003); *Westralia* (Aug 2003)	Not recorded
Clytia hummenlincki	*Dechaineux* (Aug 2003	Not recorded
Heteromysis brucei	*Westralia* (Aug 2003) & (Dec 2003)	Not recorded
Megabalanus ajax	*Darwin* (Dec 2003)	First recorded in QLD 1990
Megabalanus coccopoma	*Adelaide* (Jul 2003); *Darwin* (May 2003); *Hawkesbury* (Nov 2003); *Manoora* (Nov 2003); *Sheean* (Dec 2003)	First recorded on *Leonardo da Vinci* at Geraldton WA, in 2002
Megabalanus occator	*Adelaide* (Jul 2003); *Canberra* (Oct 2003); *Darwin* (Dec 2003); *Parramatta* (Nov 2003); *Warramunga* (Oct 2003); *Westralia* (Aug 2003) & (Dec 2003)	First recorded in WA in 1998
Megabalanus zebra	*Dechaineux* (Nov 2001) & (Aug 2003)	First recorded at Botany Bay in 1998
Metopograpsus messor	*Sydney* (Aug 2003)	Not recorded
Pachygrapsus propinquus	*Sydney* (Aug 2003)	Not recorded
Paracaprella pusilla	*Brunei* (May 2004); *Dechaineux* (Aug 2003); *Melville* (May 2004); *Wewak* (May 2004); *Whyalla* (May 2004)	Not recorded
Paralentia annamita	*Westralia* (Aug 2003) & (Dec 2003)	Not recorded
Parasabella aulaconota	*Brunei* (May 2004); *Melville* (May 2004); *Whyalla* (May 2004)	Not recorded
Pilumnus sp.	*Sydney* (Aug 2003)	Not recorded
Triperopus mirus	*Brunei* (May 2004); *Melville* (May 2004)	Not recorded
Metopograpsus latifrons	*Wewak* (May 2004)	Not recorded from Solomon Is.
Scaeochlamys livida	*Arunta* (Jun, 2008)	First recorded in Cockburn Sound in 1985
Siriella denticulate	*Warramunga* (Oct 2003)	Not recorded in WA

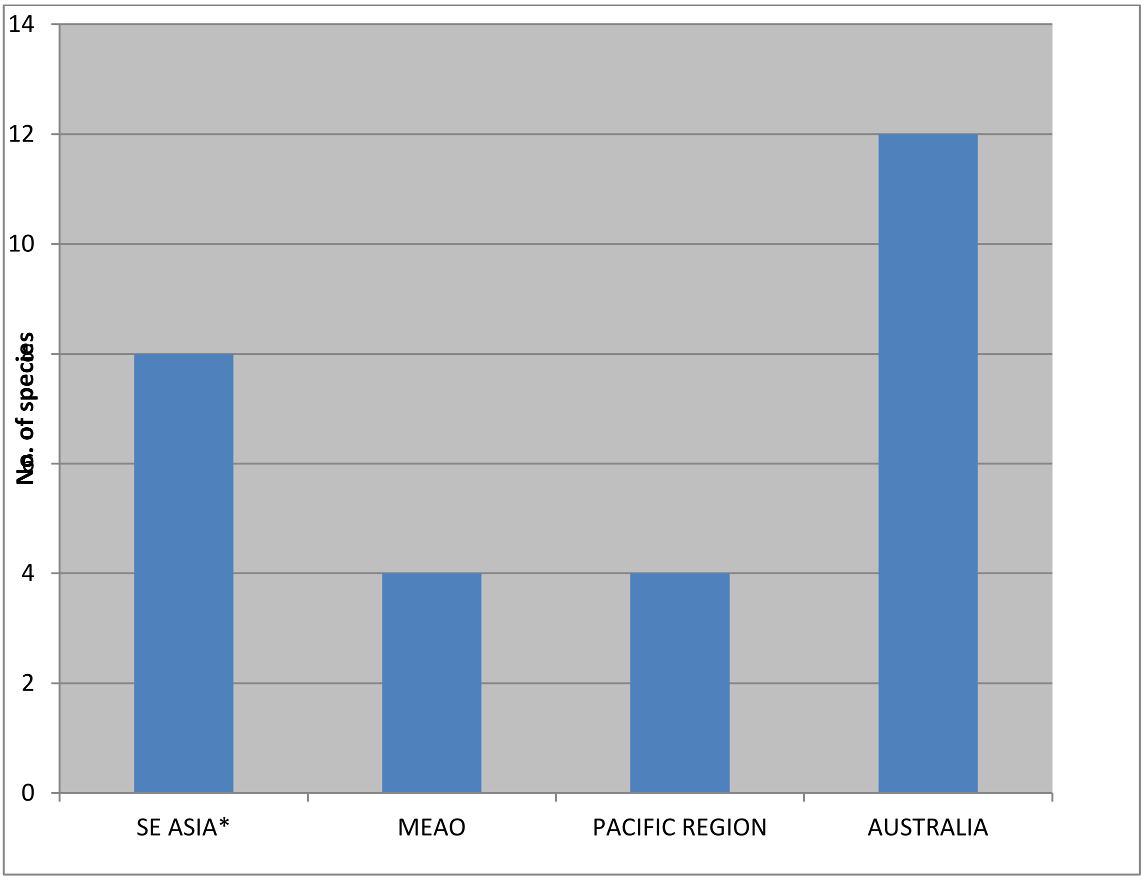

*Figure 2. NIMS identified have been grouped into four regions according to the areas visited by RAN vessels. Note: Christmas Island has been included with *SE Asia due to its close proximity.*

Table 2. NIMS sampled from RAN ships considered new or recent introductions, with ship name, date of inspection, and previous ports of call

NIMS species	Ship (class) HMAS	Date of Inspection	Previous Ports of Call ***Inspection Port***
Megabalanus coccopoma; Megabalanus occator	*Adelaide (FFG)*	10 July 2003	Broome, FBW, Chennai, Singapore, ***FBW***
Caprella californica	*Anzac (FFH)*	24 July 2003	Fremantle, ***FBW***
Scaeochlamys livida	*Arunta (FFH)*	30 June 2008	FBW, MEAO, **FBW**
Hydroides sanctaecrucis; Paracaprella pusilla; Parasabella aulaconota; Triperopus mirus	*Brunei (LCH)*	9 May 2004	Coastal Nth Queensland, **HMAS *Cairns***
Megabalanus occator	*Canberra (FFG)*	27 Oct 2003	Cairns, Brisbane, FBE, ***FBW***
Megabalanus coccopoma	*Darwin (FFG)*	17 May 2003	Seychelles, MEAO, Diego Garcia, ***Fremantle***
Amphibalanus zhujiangensis; Megabalanus ajax; Megabalanus occator; Megabalanus zebra	*Darwin (FFG)*	1 Dec 2003	Townsville, Gladstone, Brisbane, Adelaide, ***FBW***
Megabalanus zebra	*Dechaineux(SSG)*	16 Nov 2001	Northern Australian; SE Asia, ***FBW***
Megabalanus occator; Megabalanus zebra; Paracaprella pusilla; Clytia hummelincki; Balanus pulchellus	*Dechaineux (SSG)*	1 Aug 2003	Singapore, Darwin, ***FBW***
Caprella californica; Megabalanus coccopoma	*Hawkesbury (MHC)*	24 Nov 2003	Solomon Is., Hobart, Melbourne, **HMAS *Waterhen***
Hydroides sanctaecrucis	*Ipswich(FCPB)*	9 May 2004	Darwin, Ballina, Brisbane, **HMAS *Cairns***
Megabalanus coccopoma; Megabalanus occator	*Manoora (LPA)*	10 Nov 2003	Townsville, Honiara, Townsville, ***FBE***
Parasabella aulaconota; Paracaprella pusilla; Triperopus mirus; Hydroides sanctaecrucis	*Melville (HS)*	9 May 2004	FBE, Melbourne, Hobart, Devonport, Jervis Bay, **HMAS *Cairns***
Metopograpsus messor	*Newcastle (FFG)*	2 Dec 2003	MEAO, Goa, ***Fremantle***
Megabalanus occator; Spirobranchus minutus	*Parramatta(FFH)*	16 Nov 2003	Williamstown, FBE, ***FBW***
Cancellaria sp.; Megabalanus occator	*Sheean(SSG)*	1 Dec 2003	Dampier, Darwin, Timor Sea, E. Indian Ocean, ***FBW***
Hydroides sanctaecrucis	*Shepparton (SML)*	8 May 2004	Cobourg Peninsula, Darwin, **HMAS Cairns**
Pachygrapsus propinquus; Pilumnus sp.	*Sydney (FFG)*	17 Aug 2003	MEAO, ***Fremantle***
Megabalanus occator;	*Warramunga (FFH)*	6 Oct 2003	Darwin Pearl Harbour, Noumea, ***Dunedin***
Caprella californica; Heteromysis brucei; Megabalanus occator; Paralentia annamita	*Westralia (AO)*	1 Aug 2003	FBW, Broome, Christmas Island, ***FBW***
Heteromysis brucei; Megabalanus occator; Paralentia annamita	*Westralia (AO)*	12 Dec 2003	Alongside **FBW,**
Hydroides sanctaecrucis; Metopograpsus latifrons; Paracaprella pusilla; B. pulchellus	*Wewak(LCH)*	9 May 2004	Solomon Is., **HMAS *Cairns***
Branchiomma cf. bairdi; Paracaprella pusilla; Parasabella aulaconota; Hydroides sanctaecrucis	*Whyalla(FCPB)*	8 May 2004	Port Essington, Darwin, Thursday Island, **HMAS *Cairns***

4. Discussion

4.1 Defence-Restricted Ports

Defence-only ports may be subject to different invasion pressures compared to commercial ports due to differences in operational procedures. This may make defence ports more susceptible to certain NIMS compared to commercial ports, allowing certain species to become dominant providing a unique environment for the colonisation of NIMS and an inoculation point for RAN vessels.

Temperate Ports

4.1.1 HMAS *Stirling*, Fleet Base West (FBW)

HMAS *Stirling* is located on Garden Island Western Australia more commonly referred to as FBW, and separated from the mainland by Cockburn Sound, south of Fremantle and Perth. FBW has an internal port on the eastern shore, with three main wharfs restricted to defence vessels. There are numerous other artificial structures including an armaments jetty and mariculture facility around the northern tip of the island however the rest of the coastline is relatively undisturbed. While FBW is a temperate port, the waters surrounding it are influenced by the Leeuwin Current which at different times of the year brings warm low-salinity water southward along the WA coastline. Many of the RAN vessels berthing at FBW had returned from SE Asia, several stopping along the northern coastline of Australia and not surprisingly, species identified on the vessels berthed at FBW were predominately tropical species, whose chances of survival are increased due to seasonal warm water effects from the Leeuwin current (McDonald, 2012).

4.1.2 HMAS *Kuttabul*, Sydney Harbour, Fleet Base East (FBE)

HMAS *Kuttabul*, including Garden Island dockyard immediately adjacent, together take on the designation of Fleet Base East situated in Sydney Harbour. HMAS *Kuttabul* was established in 1856 and has been under the control of RAN since then. HMAS *Kuttabul* is contiguous with the mainland including commercial and recreational ports located nearby. *M. coccopoma* was identified on a piling in port in 2010 and is unlikely to be an incursion limited to Defence sites, with a high likelihood there are other colonies situated in the surrounding bay which include commercial and recreational ports. This would pose a biosecurity issue for all vessels in the area, not only for defence vessels berthing at HMAS *Kuttabul*.

4.1.3 HMAS *Leeuwin*, Fremantle

HMAS *Leeuwin* is located in Fremantle, Western Australia and first commissioned as the naval depot for Fremantle in 1940. While control of the base was handed over to the Australian Army in 1987, the RAN maintains control of the wharves and boatsheds, and in this survey several of the FFGs berthed here after their return from the MEAO. The predominate NIMS found on the vessels were three species of decapods, originally from the MEAO and one barnacle species, *M. coccopoma*.

Tropical Ports

4.1.4 HMAS *Cairns*, Trinity Inlet (T.I.)

HMAS *Cairns* is located on the northern shore of Trinity Inlet in Cairns QLD, and is the home port for 14 RAN vessels, several of which carry out domestic duties. The port also provides refit and training support for Pacific Class Patrol Boats from neighbouring Pacific Island Nations. Although used regularly as a port of call since WWII a permanent RAN presence was not established until 1971. HMAS *Cairns* is responsible for all Australian naval activity off the north-eastern Australian coast from Rockhampton to Thursday Island. Several NIMS, particularly fouling polychaetes *B. bairdi* and *P. aulaconota*, have been subsequently identified from surrounding areas around the port (Lewis et al., 2006). There are no geographical or physiological barriers separating HMAS *Cairns* from non-defence ports situated along Trinity Inlet, allowing NIMS to spread throughout the area, including commercial and recreational ports posing a biosecurity issue for all vessels in the area.

4.2 Species

Most of the species identified in the hull biofouling survey have a long association with Australian waters, and are well documented with regards to their presence as nuisance biofoulers on vessel hulls and their effects on the environment. The biosecurity status in Australia of the NIMS identified as a subset of this survey and the vessel/s they were identified on are listed in *Table 1.*

In this report only recent or new introductions will be examined in depth. The names of the NIMS, the vessel, the date of inspection and previous ports of call are listed in *Table 2*. The ports at which each inspection was carried out for the vessel have been underlined.

4.2.1 Recent Introductions of NIMS Recorded Prior to Survey

In this survey, recent introductions constitute species that have been recorded in Australia by other surveys within the last 2-20 years. Longer-term introductions greater than 20 years allow a comparison against recent introductions to help better understand potential behaviour in a new environment, and the biosecurity risk posed to Australia.

4.2.1.1 Hyrdroides sanctaecrucis (tube worm)

H. sanctaecrucis is a tropical species originally from Saint Croix and Caribbean Sea, and now found in the Atlantic Ocean, the Gulf of Mexico, Panama, and the Pacific Ocean including Hawaii (Long, 1974). This species was first identified in Australia on the hull of Indonesian Tall Ship *Dewa Ruci* in 1998, and six months later at Cullen Bay Marina, Darwin NT. Prior to this survey, *H. sanctaecrucis* was identified on HMAS *Brunei* and HMAS *Labuan* in 2001 while docked in the Port of Cairns, North Queensland (Lewis et al, 2006). In this survey, *H. sanctaecrucis* was identified in biofouling from six of the seven vessels local to Trinity Inlet which confirms this species has become established in Trinity Inlet from at least 2004.

4.2.1.2 Megabalanus ajax (barnacle)

M. ajax was first recorded from the Indo-west Pacific (Henry & Mclaughlin, 1986), and is one of the less invasive species in this genus (Jones, 2003). It was first recorded in Australia on the Great Barrier Reef (GBR) in 1990 (Jones 1992). In this survey, *M. ajax* was only found on one vessel, HMAS *Darwin* (Dec 2003) travelling from northern Queensland along the eastern coast of Australia, berthing at FBW. Despite it being a tropical species, it survived the voyage due to warmer temperatures along the southern coastline of Australia encountered during December which helped mitigate cold water effects encountered on the voyage to FBW. At the time of the survey there was no evidence a colony had established at FBW, and it is unlikely a tropical species such as *M. ajax* would establish in a temperate port such as FBW.

4.2.1.3 Megabalanus occator (barnacle)

M. occator is a tropical species first recorded in Australia in a survey of Port Hedland in 1998 the likely vector being shipping (Jones, 2003, 2008). It was the most prolific species in this survey subset, recorded on nine vessels, three of which remained in Australian waters and in one case a second inspection of a vessel after remaining alongside at FBW for five months. Whether spawning occurred between the first and second inspection resulting in settlement at FBW cannot be determined. With no record of this species from subsequent port surveys of FBW it seems unlikely. In 2005, *M. occator* was listed as a new and recent introduction that had not become established in Australian waters (Sliwa et al., 2005). By 2009 it was recorded from Barrow Island, Dampier Archipelago and Broome as well as eastern Australian ports (Wells and McDonald, 2009, 2010). In 2010 it was record at Willie Creek north of Broome in WA (D. Jones unpublished data) and Shark Bay, WA in 2011 (Oceanica, 2011). Despite its expansion along the northern coastline of Australia, *M. occator* is not on the CCIMPE list (Appendix A) or D.o.A. list of invasive species (Appendix B) however the propensity of *M. occator* for hull biofouling would indicate a potential risk, primarily along the northern Australian coastline, that requires further attention.

4.2.1.4 Megabalanus zebra (barnacle)

M. zebra is a known hull fouling species (Pollard & Pethebridge, 2000b). It was identified on HMAS *Dechaineux* (Nov 2001) and (Aug 2003) with the most likely region of infestation being Singapore and SE Asia, where *M. zebra* is known to occur. *M. zebra* was also identified on HMAS *Darwin* (Dec 2003) which remained in Australian waters travelling south along the Queensland coastline stopping at Townsville, Gladstone and Brisbane then travelling to South Australia and stopping at Adelaide before returning to FBW. There are no records of *M. zebra* for the FBW area at the time of this survey and the only Australian records for this species are recorded along the east Australian coastline, NSW in 1998 and 2000 (Jones, 2004). This indicates the presence of local colonies of *M. zebra* in at least one of the ports visited by HMAS *Darwin* (Dec 2003) along the Queensland coastline at the time of this survey, and the likely translocation to FBW. Currently, there are no reports of *M. zebra* in any of these ports. One possible explanation is that any potential colonies along the east coast of Australia were transient, while colonisation of FBW was unsuccessful.

4.2.1.5 Megabalanus coccopoma (barnacle)

M. coccopoma is native to the tropical eastern Pacific Ocean and has previously been misidentified as *M. tintinnabalum,* so its presence in Australian and international waters

may have been under-reported. *M. coccopoma* has established in the western Atlantic, north-western Europe and Japan. The first Australian record of a vessel carrying *M. coccopoma* was by the dredge *Leonardo da Vinci* in Geraldton WA in 2002, after making its way across the Panama Canal. With a vessel in the port of Geraldton implicated in the first recorded incursion in Australian waters in 2002, surveys of the area were carried out in 2003 and 2007, which failed to locate *M. coccopoma* in Geraldton. However, in this survey *M. coccopoma* was identified on 4 of the survey vessels, all of which travelled internationally, with some travelling to overseas areas where colonies of *M. coccopoma* were not officially recorded before returning to Australia. This may indicate that the infestation did not occur overseas and we cannot dismiss the possibility that *M. coccopoma* may have been a domestic infestation prior to or on return from overseas travel. *M. coccopoma* was identified in surveys in 2009 from Newcastle, Port Kembla, Pittwater and Point Hacky along the eastern coastline of Australia. Furthermore, bulk carriers from the east coast of Australia were implicated as vectors for the introduction of *M. coccopoma* to Japan in 2005 (Yamaguchi, et al., 2009), which infers the presence of local colonies in Australian waters prior to 2005. This is in agreement with Crickenberger (2013) who has stated that colonies were present in Australia since at least 2006. While there is evidence to indicate colonisation of the east coast of Australia by M. coccopoma, the original incursion at Geraldton in WA appears to have been handled effectively with no other record of *M. coccopoma* along the WA coastline (Wells et al., 2009). The likelihood is the infestation of the vessels in this survey did not occur while travelling south along the WA coastline, and berthing at FBW, but occurred while the vessels were overseas. To date there is no record of this species at FBW or surrounding areas, so colonisation remains unsuccessful despite the translocation of *M. coccopoma* to the port at FBW at the time of this survey.

4.2.1.6 Megabalanus rosa (barnacle)

M. rosa is native to Japan, but has been recorded in China and Taiwan (Henry & McLaughlin, 1986), and is known to have been introduced to Australian waters from Japan (Pollard and Pethebridge, 2002a). The first recorded appearance of this species in Australia was in Western Australia in 1981, since then it has been recorded from three sites in the Dampier Archipelago and eastern Australian waters and more recently from major ports in northern and eastern Australia (Jones, 2003, 2004). These areas cater to international shipping, making it the most probable vector. *M. rosa* has a distribution in Australia which includes: Western Australia (Shark Bay, Carnarvon, Barrow Island, the Dampier Archipelago, Port Hedland, and Cockatoo Island) (Burbidge and Scott, 2005) and NSW (Wollongong, Port Botany and Port Kembla) (Pollard and Pethebridge, 2002b). *M. rosa* has been designated as an Introduced Marine Pest (IMP) by the National Introduced Marine Pest Coordination Group (NIMPCG), and is considered a cosmopolitan fouling species (D.o.F, 2006). *M. rosa* was identified on HMAS *Dechaineux* in 2001, and while considered a nuisance fouler it was not a prevalent species in this survey. Its longer association with Australian waters compared to many of the other barnacles species identified in this survey, gives us a better understanding of its behaviour in Australian waters and any potential threat to biosecurity is considered minor.

4.2.1.7 Scaeochlamys livida (mollusc)

S. livida is endemic to the east coast of Australia and considered a non-indigenous species in Western Australia. This species was first recorded in Cockburn Sound around 1985, a new incursion which is believed to have displaced the native scallop species *Mimachlamys*

asperrima (Morrison & Wells, 2008). Surveys conducted in 2007 showed an increase in *S. livida* in the areas around Cockburn Sound (McDonald and Wells, 2009). In this survey, *S. livida* was only identified on one vessel HMAS *Arunta* (Jun, 2008), prior to 2004, this species had not been identified on RAN vessels. This may be indicative of its increase in numbers in the areas around FBW and Cockburn Sound over this period. The likelihood is this species was present at FBW and attached to the vessel on its return from the MEAO in May 2008. The survey was carried out at the end of June, providing ample time for S. livida to settle and grow on hull fouling on HMAS *Arunta*.

4.2.1.8 Spirobranchus minutus (polychaete)

S. minutus is a temperate species native to the Gulf of Mexico, and its range extends from the Caribbean to Brazil and Hawaii. It was first recorded in Australia on the German barque "Gorch Flock" in Botany Bay, NSW in 1990 (Lewis et al., 2006), and is known to co-occur with *S. taeniatus*, a species common along the eastern Australian coastline (ten Hove, personal communication, 2011). In this survey, *S. minutus* was identified on HMAS *Parramatta* (Nov 2003), which had spent over 12 months in Williamstown and Sydney prior to travelling back to FBW. The likelihood is that there are local colonies along the eastern coastline of Australia, and whether colonisation resulted after the initial incursion in 1990 or subsequent incursions is unknown. *S. minutus* has been listed as potentially invasive (IPI, 2013), and while it is a rapid coloniser of bare spaces, once established, its poor competitive ability coupled with a slow growth rate and small tube size, limits its invasive potential reducing any environmental impact (Garcia and Salzwedel, 1995). Currently there are no records of *S. minutus* at FBW so it is unlikely colonisation was successful.

4.2.2 First occurrence in Australia recorded by the RAN Hull Survey

Several species in this survey had not previously been recorded in Australian waters, an indication they may be new arrivals or possibly previous incursions into Australian waters which have escaped detection by port surveys. This is not unexpected when conducting port surveys assessing large areas which have intensive requirements for the isolation and identification of a large number of species which can result in some species being overlooked.

4.2.2.1 Amphibalanus zhujiangenesis (barnacle)

A. zhujiangensis is a sub-tropical species native to the Zhujiang River estuary in the south of China (Chan, 2011; Otani et al., 2007). It had previously been recorded in Japan in 1997, 2001 and Indonesia in 2001 (Puspasari et al., 2002). At the time of this survey, *A. zhujiangensis* had only recently (2 months) been recorded for the first time in Australia at Eden, NSW in 2003 on fixed infrastructure in the port (Pollard & Rankin, 2003). In this survey, *A. zhujiangensis* was recorded on two vessels, HMAS *Dechaineux* (Aug 2003) returning from Singapore and stopping at Darwin before berthing at FBW and HMAS *Darwin* (Dec 2003) travelling south from Townsville along the eastern coast of Australia and berthing at FBW. At the time of the survey, *A. zhujiangensis* had not been recorded in any port surveys for either FBW or Darwin, but had been recorded in South China Sea and regions around the Tropical East Indonesia (Prabowo, 2011) making Singapore a likely point of infestation for HMAS *Dechaineux* (Aug 2003). However, HMAS *Darwin* (Dec 2003) remained within Australian waters, indicating the possibility of local disjunct colonies

along the NSW/Queensland coastline not previously identified and responsible for the infestation of HMAS Darwin (Dec 2003). A. *zhujiangensis* is known to attach to *Megabalanus* species (Chan, 2010) and this may have facilitated its translocation into Australian waters. With the identification of *A. zhujiangensis* in subsequent surveys of Gove Harbour and Groote Eylandt, NT from 2007 to 2012 (not in 2013), indicating its presence in this region over the last 5-6 years and given this species' tropical physiology, the northern Australian coastline is a likely target area for colonisation (Cribb et al., 2007, 2008, 2009, 2010, 20011, 2012, 2013). It is difficult to predict the impact of *A. zhujiangensis* as there is sparse literature on its behaviour outside its native range in China, but it is related to the barnacle *A. amphitrite*, which has a long association with Australia, indicating it may exhibit similar characteristics in colonisation. Currently advice is that *A. zhujiangensis* is not likely to become an environmental problem (John Lewis personal communication, 2012).

4.2.2.2 Balanus pulchellus (barnacle)

B. pulchellus is a subtropical species native to the Zhujiang River estuary which empties into the South China Sea, and was identified on HMAS *Dechaineux* Aug (2003) and HMAS *Wewak* May (2004). HMAS *Dechaineux* (Aug 2003) visited Singapore and Darwin before returning to FBW. The most likely infestation point is Singapore, considering this regions close proximity to the South China Sea, also coupled with the fact that at the time of the survey there was no record for *B. pulchellus* in Australia. HMAS *Wewak (*May 2004) based at Trinity Inlet, in northern QLD, travelled to the Solomon Islands before returning to Trinity Inlet and with no record of *B. pulchellus* for either of these two regions it is difficult to determine where the incursion occurred. However, considering HMAS *Wewak* (May 2004) spent a larger percentage of time in Australian waters, and the trip to the Solomon Islands was a short-stay voyage, the probability of the presence of colonies of *B. pulchellus* along the northern coastline of Queensland is more plausible. Subsequent to this survey, *B. pulchellus* was recorded in a survey of Fremantle Port waters in 2012, and this species had been targeted for "possible presence" by the Department of Fisheries (D.o.F) WA, in 2011/12. It is possible there may be other disjunct colonies of *B. pulchellus* around the Australian coastline not yet identified.

4.2.2.3 Branchiomma bairdi (polychaete)

B. bairdi is a tropical species native to the Caribbean Sea and the Gulf of Mexico, where high seasonal peaks have been responsible for clogging intake pipes of vessels in port Tovar-Hernandez et al, 2006). This, coupled with its rapid range expansion and high fecundity, has raised concerns overseas. In this survey *B. bairdi* was identified from four vessels local to HMAS *Cairns* and also travelling to regions along the northern Australian coastline. The presence of *B. bairdi* on local vessels travelling nationally indicates the presence of *B. bairdi* in local benthic communities in this region, with the possibility of disjunct colonies, not yet identified, in ports along northern Australia. Also, unofficial reports of the presence of *B. bairdi* along the northern Queensland coastline go back up to ten years (Maria Capa personal communication, 2012). There was further confirmation when several specimens of *B. bairdi* were collected from settlement ropes at Trinity Inlet situated alongside HMAS *Cairns* in QLD in 2008 and 2010 (Montelli, unpublished results). Hull biofouling is the most likely vector for the introduction and colonisation of this species in tropical regions (Tovar-Hernandez & Dean, 2010), with *B. bairdi* having a high propensity for attachment to vessel hulls, and its presence on four of the local vessels would validate its propensity for range expansion via hull biofouling. The biosecurity

impact from this species in Australia is unknown and will require further observation to ensure it does not detrimentally affect the environment and become a nuisance biofouler on vessel hulls and in ports (Tovar-Hernandez & Knight-Jones, 2006).

4.2.2.4 *Saccostrea cucullata; Planostrea pestigris (bivalves)*

Five species of bivalves from vessels berthed at FBW were identified by Richard Willan from the Museum and Art Gallery of the Northern Territory (MAGNT). These were; *Saccostrea cucullata, Planostrea pestigris, Pteria cooki, Placamen clophylla, Nassarius glans, Pinctada sp.* and *Timoclea sp*. These bivalves are found in east Australian waters but are uncommon at FBW in southern WA. Notably, the differences in environmental conditions at FBW as well as those encountered *en route* back to Australia are the likely cause, for the 100% mortality rate these species suffered. This highlights range limitations for certain species for particular regions or zones (Cribb et al., 2007).

4.2.2.5 *Cancellaria sp. (Bivalves)*

The only non-indigenous molluscan species in the RAN survey belonged to the genus *Cancellaria* (Willan personal communication, 2012.). With many species from this genus known from the Eastern Indian Ocean, this species is likely to have attached to HMAS *Sheean* (Dec 2003) while traversing the Timor Sea and into the East Indian Ocean before being transported back to FBW. This specimen was deceased at the time of collection therefore posing no threat.

4.2.2.6 *Caprella californica (caprellid)*

C. californica was first recorded in Botany Bay NSW in 2002, and since then it has increased its range to include several major ports along the Australian coastline including FBW (Montelli, unpublished 2008). *C. californica* was identified from three vessels in this survey. Two vessels, HMAS *Anzac* (Jul 2003) berthed at FBW for approximately two months while HMAS *Westralia* (Aug 2003) returned from Christmas Island, stopping at Broome and then continuing south along the WA coast and berthing at FBW. Concurrently with the RAN survey, a port survey at FBW conducted by the RAN Regional Environmetal Officers at FBW with samples identified by DST Group initially confirmed there were no specimens of *C. californica* present at FBW at the time of this survey (Montelli, unpublished results). However, from approximately 2005 onwards there was a substantial increase in the next several years, with large numbers now a seasonal occurrence (Montelli, 2010). The third vessel HMAS *Hawkesbury* (Nov 2003) travelled to the Solomon Islands, along the south-eastern coast of Australia, berthing at HMAS *Waterhen*, NSW. The most likely incursion point, for this vessel would have been along the south-eastern coast of Australia where low numbers of *C. californica* have been recorded along the east coast (Montelli, unpublished results). Though the initial incursion of *C. californica* occurred on the east coast of Australia, translocation to southern WA, specifically FBW, is likely to have occurred via hull biofouling, with RAN vessels the most likely vector. The large proliferation of this species at FBW could not have been predicted based on its behaviour on the east coast of Australia and may partly be explained by instability in the ecosystem at FBW common in man-made ports, coupled with favourable conditions unique to the west coast of Australia allowing this species to proliferate. The environmental impact of *C. californica* on native and endemic species in the area is unknown but interestingly it exhibits aggressive behaviour towards other species of caprellids (Caine, 1977). Operationally, large numbers of *C. californica* could clog intake vents on RAN vessels but

its small size and fragility is unlikely to cause any major problems, however further research would be required to determine any environmental impact on the local area.

4.2.2.7 *Clytia hummelincki (hydroid)*

C. hummelincki is a circumtropical species native to the West Indies and the Caribbean Sea, and is widespread in the warmer parts of the Atlantic Ocean where it is most abundant in the summer months (Cornelius, 1982; Gravili & Belmonte, 2010). The first record for the Mediterranean region was in 1996, followed by Indonesia, Malaysia and Singapore in 2001 (Streftaris et al, 2005). The rapid expansion of *C. hummenlicki* is due to a high dispersal capacity in the medusa stage (Occhipinti & Marchini, 2010; Ozturk & Isinibilir, 2010), and its effectiveness as a predator as well as competitor (Boero et al., 2005; Govindarajan et al., 2006). *C. hummelincki* was identified on HMAS *Dechaineux* (Aug 2003) returning from Singapore, stopping at Darwin, and berthing at FBW. The incursion is likely to have occurred in Singapore with the translocation of *C. hummelincki* to Darwin Harbour. Surveys of Darwin Harbour in 2008 detected the presence of *C. hummelincki*, (Cribb et al., 2008-09) however a subsequent survey in 2010 did not, indicating either a transient colony or possibly the port survey overlooked this species. With a reputation as an "inconspicuous" hydroid, identification is easily overlooked by non-specialists. Regardless, *C. hummelincki* is unlikely to have colonised at FBW, as a tropical species, its target area is along the northern coastline of Australia and to date there have been no further records of this species in Australian waters.

4.2.2.8 *Heteromysis brucei (mysid)*

H. brucei is native to New Zealand with a distribution that includes the tropical coastal waters of the Pacific and Indian Ocean and Seychelles. Common along the east Australian coastline, it was first recorded in Australia prior to 2002. It was identified on HMAS *Westralia* (Aug 2003) which berthed at FBW, after returning from Christmas Island and Broome and on a second inspection after the vessel after being alongside at FBW for several months. With no records of *H. brucei* for either Darwin or Christmas Island it is difficult to determine where the incursion occurred. The presence of *H. brucei* on HMAS *Westralia* Aug (2003) for both inspections several months apart indicates colonisation of the vessel hull and this specie's propensity for hull biofouling. With no other records of *H. brucei* in any port surveys in the local area, there is no evidence to suggest the establishment of colonies in the port at FBW. The likelihood is that *H. brucei* persisted in hull biofouling on HMAS *Westralia* (Aug 2003) where it was identified in the second hull inspection, but did not colonise the port. The impact from this species on the west coast of Australia is unknown, but if it is similar to the east coast, its effect should be negligible.

4.2.2.9 *Metopograpsus messor (decapod)*

M. messor is native to the Gulf of Suez, and while predominately an Indian Ocean species it is known to occur in the Red Sea (Hartoll, 1975), and is commonly found amongst oysters, in fouling and under rocks. *M. messor* was identified from HMAS *Newcastle* (Dec 2003) on manoeuvres in the MEAO, including the Persian Gulf and other regions surrounding the Red Sea. Given this species natural range, the MEAO is where the incursion is likely to have occurred. The practice of anchoring off shore and slow-speed patrolling undertaken by RAN vessels in this area would have provided *M. messor* ample opportunity to "climb on board". Despite undergoing a long trans-oceanic voyage back to Australia on RAN vessels, this species survived, which in part may be due to the advantages of being motile

allowing it to mitigate harsh conditions by moving to different locations and seeking out a more conducive environment for survival. While *M. messor* is suited to Australian waters, competition from local Australian species in this genus occupying the same ecological niches would out-compete *M. messor* indicating a low impact factor and negligible risk from this species (Peter Davies personal communication 2004). While this species constitutes negligible risk for the biosecurity of Australian waters, it is a good example of the opportunistic nature of certain species and their ability to survive the translocation process by manipulating their environment.

4.2.2.10 Paracaprella pusilla (caprellid)

P. pusilla is a tropical species native to Rio de Janeiro, Brazil and now common along the Atlantic coast of Central America, Caribbean coast of Venezuela and Colombia. It is one of the most abundant and widespread amphipod species in tropical and sub-tropical seas around the world (Diaz et al., 2005; Bhave et al., 2009). The first occurrence in European waters was in southwestern Spain in 2010, followed by Mallorca in November 2011 and Ibiza in August 2012 with the most probable vector being ship fouling (Ros et al., 2013). *P. pusilla* is commonly associated with artificial substrates such as ropes, buoys, pontoons and oil platforms, and has demonstrated it is capable of invasive behaviour overseas. *P. pusilla* was identified on HMAS *Dechainuex (*Aug 2003), HMAS *Brunei* (May 2004), HMAS *Melville* (May 2004), HMAS *Wewak* (May 2004) and HMAS *Whyalla* (May 2004). HMAS *Dechaineux* (Aug 2003), travelled to Singapore and Darwin before berthing at FBW and with no records of *P. pusilla* in any of the port surveys conducted at FBW, it is unlikely that a tropical species would successfully colonise a temperate port. The last four vessels were local to HMAS *Cairns* in Trinity Inlet but also undertook patrols along the northern coastline of Australia. Identifying *P. pusilla* on four local Trinity Inlet vessels would indicate the presence of isolated local disjunct colonies along the northern coastline of Australia in particular Trinity Inlet in Cairns Harbour and surrounding areas. However, subsequent port surveys conducted in Darwin, and the Great Barrier Reef and surrounding areas failed to identify this species (Guerra-Garcia, 2006). While there were no records for *P. pusilla* in this region at the time of the survey (2004), subsequent port surveys of Trinity Inlet in 2009 have identified *P. pusilla* and confirmed its presence (Montelli, unpublished results). Most likely there are local disjunct colonies that have gone undetected at Trinity Inlet. While it is known to be a pervasive species overseas, particularly in the Mediterranean Sea, the small number of specimens identified from this biofouling survey and subsequent port survey of Trinity Inlet in 2009 would indicate the threat posed by this species is currently low, but may need further monitoring to better assess the biosecurity risk.

4.2.2.11 Paralentia annamita (polychaete)

P. annamita is native to Vietnam, but has a wide distribution which includes the Indian Ocean, Indo-West Pacific and North West Pacific (Barnich et al., 2004; Hanley, 1991; Imajima, 1997). It was first identified in Australia on hull biofouling from HMAS *Westralia* (Aug 2003) after returning from Christmas Island and Broome and berthing at FBW. A second inspection of HMAS *Westralia* (Dec 2003) again identified *P. annamita* after the vessel had been alongside at FBW for several months. It is difficult to determine where the incursion occurred as there are no port survey records that have identified *P. annamita* at either Christmas Island or Broome. This may be due to the paucity of port surveys and the data available rather than the absence of the species. Christmas Island's involvement as a

site for the impounding of illegal fishing boats, including several from Vietnam where *P. annamita* is found, makes Christmas Island a likely candidate as a possible incursion point. The presence of *P. annamita* in the second inspection after the vessel had been alongside at FBW for several months indicates the colonisation of the hull by *P. annamita*. Another possibility is the presence of a local colony in port which re-colonised the vessel while it was alongside at FBW, but there are no records of *P. annamita* in any subsequent port surveys of FBW (Hewitt et al, 2010), making it unlikely, unless numbers are so small that they have escaped detection by port surveys.

4.2.2.12 Parasabella aulaconota (polychaete)

P. aulaconota is native to Japan but is also found in the Philippine Islands and Indian Ocean (Hartman, 1965). It is suited to temperate and sub-tropical waters. *P. aulaconota* was identified from three vessels, HMAS *Brunei (*May 2004), HMAS *Melville* (May 2004) and HMAS *Whyalla* (May 2004), all based at HMAS *Cairns*, Trinity Inlet. There are no current records for this species in Australia, however a specimen collected in March 1986 from Sydney Harbour was identified as *P. aulaconota* by Murray in 2011 (AMBS, 2013), indicating a longer association with this species in Australian waters than first indicated in this survey. Port surveys conducted in Sydney Harbour in 2002 (AMBS, 2002) were unable to detect the presence of *P. aulaconota*, an indication that colonisation of Sydney Harbour from the 1986 incursion did not occur. Based on its native distribution, this species is suited to environmental conditions along the northern Australian coastline. Its appearance on several local RAN vessels at Trinity Inlet indicates the presence of small disjunct colonies in this region, whether these colonies are transient or have become established is unknown. With little evidence this species is invasive or likely to cause a problem, its impact on the biosecurity of Australia is regarded as low.

4.2.2.13 Pachygrapsus propinquus (decapod)

P. propinquus is a tropical crab and is reported to have a natural range that extends beyond its native India, and includes the Red Sea, Indian Ocean and possibly other tropical regions (Poupin et al, 2005). Other species in this genus have a wide natural tropical range, with the same expected of *P. propinquus.* Little is known about this species except that it is very common in Chililika Lagoon, and is a very active species that for the most part lives along stony foreshores and in brackish water (Sahoo, D. et al., 2008; Kemp, 1915). *P. propinquus* was identified from HMAS *Sydney* (Aug 2003) returning from the MEAO to FBW. While in the MEAO the vessel was anchored offshore in the Persian Gulf, undertaking slow-speed patrolling of the general vicinity. *P. propinquus* is known to occur in the Persian Gulf and surrounding areas making this region the likely incursion point with translocation back to FBW. Subsequent port surveys of FBW have failed to identify this species making it unlikely that colonies have established. The fact that FBW is a temperate port is one reason for the failure of this species to colonise given it is a tropical species. While there were no records of *P. propinquus* in Australia, at the time this species was identified in the RAN survey (2003), a few years after this survey (2008/2009), this species was identified in fouling from Darwin Harbour (S. Ahyong personal communication, 2013). *P. propinquus* is now common in certain areas around Darwin Harbour with large numbers observed around Cullen Bay (Golder Assocs., 2010; Hewitt & Campbell, 2010). The most likely route responsible for the colonisation of Darwin Harbour is the India Ocean. Currently, *P. propinquus* is still restricted to areas around Darwin Harbour where increasing population numbers and range expansions can be monitored.

At this time the threat posed by this species to temperate ports such as FBW, is low, but further monitoring is required to limit any range expansion to more tropical areas along the WA coastline.

4.2.2.14 Pilumnus sp. (decapod)
The *Pilumnus* genus is widespread with several species endemic to Australian waters (Poore, et al., 2008). This *Pilumnus sp.* was identified on HMAS *Sydney* (Aug 2003) along with *P. propinquus*, increasing the probability the *Pilumnus sp*. also originated from the MEAO. The juvenile age of the specimen would indicate it had not been on the vessel for long.

4.2.2.15 Triperopus mirus (caprellid)
T. mirus is typically found in the Korean Straits (Arimoto, 1979). It was identified on HMAS *Brunei* (May 2004) and HMAS *Melville* (May 2004), both travelling in Australian waters and based at HMAS *Cairns* in Trinity Inlet. There are few records on the distribution of this species so it is difficult to determine where this incursion may have occurred. Subsequent port surveys of the Port of Cairns and surrounding areas failed to identify *T. mirus* (Guerra-Garcia, 2006). The low numbers identified in this survey indicate a transient colony on RAN vessel hull biofouling that did not establish in Trinity Inlet.

4.3 "Reverse" Translocation

In this survey, reverse translocation involved the process of vessels translocating Australian native species overseas. This demonstrates the propensity of several Australian native species to survive long journeys outside their normal environmental conditions (Panov & Gollasch, 2004). There was one example in the hull biofouling survey, where a RAN vessel transported a local species to and from the Solomon Islands. While the biosecurity risk posed by the species on this vessel was low, this demonstrates the potential for the translocation of Australian marine species overseas, and increases our awareness of the biosecurity risk which may be posed by fouled RAN vessels to environmentally sensitive and vulnerable regions overseas.

4.3.1.1 Metopograpsus latifrons (decapod)
M. latifrons is endemic along northern Queensland with records dating back to 1918. It is found predominately in mangrove areas common to this region. This species was identified on HMAS *Wewak* (May 2004) on its return to HMAS *Cairns* in Trinity Inlet after travelling to the Solomon Islands. This species is not known from the Solomon Islands, and *M. latifrons* is likely to have been transported in hull biofouling to and from the Solomon Islands without causing any detrimental effects. Unlikely though it was for this species to pose a threat to the biosecurity of the Solomon Islands due to its preference for habitats such as mangrove swamps not found in this region, this is a good example of the role of RAN vessels and vessels in general as vectors for the translocation of, in this case, Australian species overseas.

4.4 Regions Visited by RAN Vessels

Areas of operation and the risk they pose from a successful incursion by NIMS are determined by several factors, two of the most important ones are; the operational

frequency of vessels in that area and the environmental conditions and similarities between the donor region and recipient region (Hilliard and Raaymakers, 1997). The greater the biophysical similarities between the two regions the greater the likelihood a species will successfully become established in the recipient region. Other factors such as; distance between the donor and recipient region, the amount of time a vessel spends in a particular region, operational parameters including speed, time in port and cleaning regimes all affect the likelihood of a species surviving in hull biofouling to become an unwanted incursion.

4.4.1 RAN Operational Area: SE Asia[1]

The SE Asia region is a frequent destination for RAN vessels and includes operational activities and visits to several ports. The close geographical proximity of SE Asia to northern Australia coupled with similarities in environmental conditions such as sea-surface temperatures highlights the compatibility between donor and recipient region for these two areas. This increases the likelihood of successful colonisation by NIMS translocated into northern Australian waters from SE Asia, compared to temperate regions of Australia further south (Campbell and Hewitt, 2013). In particular, Darwin Harbour has seen several NIMS incursions from SE Asia identified from other surveys, become problematic and require remedial action by port authorities (Golder Assocs., 2010; Piola et al., 2012; Hewitt and Campbell, 2010).

Also, biofouling in tropical regions such as SE Asia grows quickly with differences in growth rates most noticeable on vessels berthed over weeks or months. This is relevant to RAN vessels, which unlike commercial vessels, may be required to spend a large percentage of the time static in these tropical climes. This allows accumulation of substantial amounts of biofouling, increasing the likelihood of viable translocations of NIMS back to Australia. There were six RAN vessels that visited SE Asia in this survey and seven NIMS were identified in biofouling from vessels returning from this region, representing the largest number of NIMS from the three overseas regions examined in this survey (*Figure* 2). Note: Due to the location of Christmas Island and its close geographic proximity and environmental similarity to SE Asia, grouping these two areas together provided a more cohesive picture of this region. Australian sovereignty and frequent visits by RAN vessels exposes Christmas Island to Oceanic species not normally seen in this region. Also the island's use as an impound area for illegal fishing and illegal entry vessels from SE Asia has not only raised the profile of this island politically, but also increased its exposure to a greater variety of marine species. Illegal vessels and any associated biofouling are not subject to any screening processes when detained at Christmas Island with the potential to allow incursions to go unmonitored (Parks Australia et al., 2011). Three NIMS were identified from vessels returning from Christmas Island to FBW, two species were native to SE Asia while the other was a temperate species translocated to Christmas Island from FBW.

[1] Note: For this report Christmas Island is classified as part of SE Asia when considering its marine biodiversity due to its close proximity to the Indonesian Archipelago. It is still under Australian sovereignty and under the patrol of RAN vessels.

4.4.2 RAN Operational Area: Pacific Region

The Pacific region, including Hawaii, Fiji, the Solomon Islands and New Zealand, has been a frequent and long-standing area of operations for the RAN. Historically this region provided anchorages for military vessels during World War II, including a major role played by our closest neighbour New Zealand. Much of this area and in particular the central Pacific region, including the area surrounding Hawaii, is biogeographically isolated leading to less diverse marine communities and making this region more susceptible to introduced NIMS (Hutchings, et al., 2002; Hewitt, 2002). Despite four NIMS being identified on vessels returning from this region (Figure 2), none were native species from the Pacific region. In contrast to the other two areas of operation, SE Asia and the MEAO, where RAN vessels were identified with NIMS either native or known from these regions.

4.4.3 RAN Operational Area: The Middle East Area of Operations (MEAO)

The MEAO is a relatively new area of operations for the RAN and poses its own unique fouling and environmental risks compared to SE Asia and the West Pacific. This area has come under more attention from the RAN over the last few decades, with long-term deployment including anchoring off shore combined with reduced speed during operations allowing a greater opportunity for NIMS to attach. Despite this only four NIMS were identified from three vessels returning from this region. Three of the four species were from the Red Sea region, making it obvious the incursion occurred while vessels were anchored in the area and providing good examples of species abilities to be translocated successfully over long distances using hull biofouling as a vector. Nevertheless, the number of NIMS identified on vessels returning from the MEAO was low in comparison to SE Asia despite a comparable number of visits for RAN vessels in both regions. One explanation for the low number of NIMS identified in biofouling from the MEAO vessels may be a result of undergoing a long trans-oceanic voyage with few ports of call before arriving in Australian waters. This exposes species to a more inhospitable environment in comparison to vessels arriving from SE Asia, a shorter voyage, with several ports along the route. Also, the physical similarity and geographical continuity between the northern Australian coastline and the MEAO makes the journey less hospitable decreasing species survival rates. Similarly, any trans-oceanic voyages returning from the MEAO normally entail higher speeds due to longer journeys increasing shear-rate effects on hull biofouling. High shear-rates are better tolerated by more robust species such as barnacles and mussels as well as motile species such as crabs, while soft-bodied species are susceptible to damage or dislodgement making them less likely to survive the journey (Hewitt, 2002). This has the effect of decreasing the overall number of NIMS arriving from the MEAO, but generates a bias, due to higher mortality in certain classes or groups of species more susceptible to these conditions. This is evident for the vessels returning from the MEAO, with three of the four specimens identified as crabs, motile species able to move to more favourable niches and mitigate any detrimental conditions during the voyage. Similarly, other species, such as barnacles, utilise their hard outer shells to provide protection from hostile conditions.

4.4.4 International Translocation

The international translocation of NIMS is closely monitored by the RAN (URS, 2006), In particular, vessels arriving from high risk areas overseas are closely monitored and inspected for species listed on Australian Trigger Lists (Appendix A). The RAN vessels in this survey returning from the MEAO provide a good example of international translocation processes as species identified in hull biofouling could be traced back to the MEAO region without any ambiguity. The survey identified a direct route from infestation point, translocation and arrival in Australia waters, which selected for species robust enough to survive translocation, in this case they were predominately decapods. This may indicate that motile species are better at mitigating harsh conditions such as ranges in temperature, salinity and high speeds, responsible for detrimental effects on fragile species due to high shear rates typical on a long trans-oceanic journey from the MEAO back to Australia. While beneficial in reducing the number of species on vessels arriving from the MEAO, it can create a bias that favours certain species.

In the SE Asia region, the physical and environmental similarities to the northern coastline of Australia provide little barrier to the translocation of NIMS from this region. Coupled with shorter voyages and more frequent ports of call prior to returning to Australia, this substantially increases the probability of the survival of species arriving from SE Asia.

In the Pacific region, no native species were identified on hull biofouling of RAN vessels returning from this region. This may indicate a lack of propensity for hull biofouling by native species or an inability to survive translocation back to Australia, due to “fragile” species unable to cope with physical and environmental factors.

4.4.5 Domestic Translocation

The domestic translocation of NIMS is much more difficult to regulate, as ship movements for recreational, commercial and defence vessels around the Australian coastline, are not subject to the same strict biosecurity regulations imposed on international vessels. While guidelines for the management of national biofouling of recreational vessels are provided by the Australian Government[2], they are voluntary and implemented at the discretion of the boat owners resulting in a wide variation in cleaning regimes and the level of biofouling present on recreational vessels which determines their susceptibility to NIMS. While RAN vessels undertaking domestic duties are considered less of a biosecurity risk than RAN vessels travelling internationally, domestic travel has been implicated in range expansion (Gollasch, 2002). In Australia, the translocation of species from the northern Australian coastline to the southern Australian coastline or vice versa is unlikely to result in successful colonisation due to large differences in environmental conditions such as temperature and salinity between tropical and temperate species. But this is not as clear-cut when considering east/west translocation, where water temperatures and salinity ranges can be similar. In this case, temperate areas along eastern Australia such as NSW, Victoria and South Australia experience similar conditions to southern and central WA, the only barrier is distance. One species, *C. californica* is a good example of domestic translocation from east to west (Montelli, 2010). Initially recorded in Botany Bay NSW, and

[2] National Biofouling Management Guidelines for Recreational Vessels. An Australian Government Initiative.

present along the east coast in low numbers, it arrived at FBW and over the next few years, numbers increased dramatically. .

Along the northern coastline of Australia, it is difficult to determine which vessels are responsible for facilitating species translocations, and this includes not only defence vessels but also recreational and to a lesser extent commercial vessels, in the region also susceptible to infestation by NIMS. The colonisation of *B. bairdi* along the northern coastline of Australia is an example of translocation from one domestic site to another. *B. bairdi* was identified on Trinity Inlet RAN vessels local to far-north Queensland surrounding northern Australian coastline. While it is impossible to identify the initial site or vessel responsible for the infestation, all vessels travelling through this region would now be exposed to this species, with the potential for infestation of hull biofouling to occur. This results in vessels unknowingly spreading *B. bairdi* to other areas along the northern Australian coastline (Capa et al., 2013).

4.5 Temperate versus Tropical species

The differences in sea surface temperatures and to a lesser extent, salinity and acidity, have been shown to be important factors in limiting the spread of invasive species. The greater the environmental similarities between the donor and recipient regions the more likely colonisation will be successful.

For this reason, climate change is implicated in increasing the range expansion of certain species due to the increased southern penetration of warm water currents along the east and west coast of Australia termed 'warm-water' events (McDonald, 2012; Pearce et al., 2013). Also, the region around FBW, though temperate is influenced at certain times by the warm waters of the Leeuwin Current which makes the area sub-temperate. This has the potential to increase the range of many tropical invasive pests, increasing invasion pressure along the coastline, and conversely increasing mortality rates of temperate species. These events are also responsible for the disruption of flora and fauna of the region affording an opportunity for colonisation by tropical NIMS translocated from overseas to the northern Australian coastline (Caputi et al., 2010; McDonald et al, 2012; Stafford & Willan, 2007).

The similarities in surface sea water temperature between SE Asia and the northern coastline of Australia provide little or no barrier against the successful translocation of NIMS, and survival rates for species arriving from these regions are high (Russell & Hewitt, 2000; Russell et al., 2004). The advantage to tropical species provided by this marine habitat continuum, which extends through the Indonesian archipelago, New Guinea and the northern Australian coastline is an increase in the likelihood of surviving the voyage from SE Asia to northern Australia and colonising successfully (Summerson & Derbyshire, 2007). While tropical species are less likely to thrive in temperate waters, there were several tropical NIMS identified on RAN vessels berthed at FBW returning from SE Asia. While these conditions are less hospitable for these species, they are not always lethal (McDonald, et al., 2012). In this survey, one tropical species was identified twice on the same vessel at FBW, initially after the vessel had returned from overseas and then again after being alongside at FBW for five months. There is no evidence this species established at FBW however, subsequent travel to tropical climes with unknown translocation of

tropical species by the vessel increases the likelihood of colonisation and posed a biosecurity threat for tropical regions.

Certain species prefer water temperatures which range between tropical and temperate, known as sub-tropical species, and may be better placed to exploit certain environmental conditions or niches not suitable to either tropical or temperate species. This may explain why one species, *C. californica* has shown such a dramatic increase in numbers at FBW while only low numbers are recorded along the eastern coastline of Australia. While *C. californica* is known as a temperate species overseas, upon arriving at FBW, it has steadily increased in numbers to the point where seasonal peaks in summer number in the thousands (Montelli, 2010). This may in part, be due to the sub-tropical waters unique to FBW and the southern WA coastline, generated by the Leeuwin Current and 'warm-water' events, providing ideal conditions for *C. californica* to flourish, in contrast to the limited numbers in the more temperate waters along the southern east coast of Port Philip Bay, Victoria, Botany Bay, NSW and the tropical waters of Trinity Inlet (Montelli, unpublished results).

5. Conclusion

Defence vessels are not necessarily more of a biosecurity risk to Australian waters compared to other vessels, rather differences in operational procedures peculiar to defence vessels most notably for international travel, makes them a different threat. Recognition of these differences is useful in determining and managing mitigation strategies.

5.1 Species

Although this survey identified fifteen previously unrecorded NIMS, only nine of these species are known nuisance foulers overseas. With eight unlikely to have colonised, one species *C. californica* currently has an established population at FBW which can be attributed to a RAN vessel incursion. However, this species does not have a high affinity with hull biofouling, with little evidence this species will prove a nuisance fouler for RAN vessels, or impact on operational procedures.

5.2 Implications from Operational Procedures by RAN Vessels

Operational manoeuvres such as off-shore anchoring for several days accompanied by slow-speed patrolling carried out by the RAN in the MEAO, provided more opportunity for species from this region to attach to vessel hulls. Most notably, three decapod species not previously found in Australia (but common in the MEAO) were identified on two vessels returning to Australia.

Long trans-oceanic voyages such as those undertaken by RAN vessels returning from the MEAO are likely to reduce the number of NIMS surviving the voyage to the Australian coastline. However, this favours the survival of more hardy, better equipped species able to tolerate hostile conditions encountered on long ocean voyages (Morton & Tan, 2006). In this survey there were three decapod species and one barnacle species hardy enough to survive the long voyage. Importantly, decapods are able to actively select for more

favourable niches to mitigate the effects of a harsh environment, while barnacles are able to enclose themselves in a protective shell and limit their exposure to harsh conditions. These strategies are useful in surviving translocation over a large range of temperatures and conditions encountered in trans-oceanic journeys, making certain species resilient enough to survive.

One operational procedure unique to RAN vessels which poses a threat to Australian biosecurity is long berthing times in home ports. Unlike commercial vessels which have relatively short turn-around times, long berthing times are common with RAN vessels and allow NIMS to acclimate and persist and in some cases to establish in hull biofouling. This increases the likelihood of colonisation of the port and translocation to other areas around Australia as well as overseas. It should not be assumed that vessels that have been berthed for several months do not pose a biosecurity risk, and vessels should be cleaned prior to any deployment, particularly if travelling to environmentally sensitive areas.

5.3 Temperate and Tropical NIMS

While tropical species are unlikely to colonise in temperate waters, and vice versa, there are instances where tropical species have survived in hull biofouling on vessels stationed in temperate waters. This survey has shown that certain tropical species are surviving voyages to temperate ports such as FBW, and while not colonising the port they are capable of surviving in biofouling present on vessels for several weeks or in some cases months. If conditions are unfavourable for tropical species to establish in port, there may be an assumption species won't survive in hull biofouling. But, in this survey there were several tropical species that were able to survive in hull biofouling for several months while berthed in port at FBW. Under certain conditions these species may become "active" when vessels sail into tropical waters, and favourable conditions encourage activation to occur, and the potential for colonisation. This scenario is as likely for either defence or non-defence vessels, and considering the various bioregions which make up the Australian coastline, all of which differ markedly from one another, this provides a variety of different conditions, more suitable in activating previously dormant species in more inhospitable conditions.

5.4 International Regions

The RAN is a frequent visitor to the SE Asia region, where several "high risk" NIMS have been recorded (Aronson et al., 2007). RAN vessels returning from the SE Asia region recorded the largest number of NIMS identified from international regions in this survey and this region poses the highest risk of an incursion (*Figure* 2.). The biosecurity threat to northern Australia from SE Asia is determined not only the number of species translocated but also the environmental similarities between the two regions, with no geophysical barriers and little variations in temperature and salinity gradients between the two. Also, the close proximity to this region and short voyage time undertaken by RAN vessels increases the chance of NIMS translocated from SE Asia surviving the voyage and colonising (Chapman & Carlton, 1991). All of these factors increase the probability of successful translocation in hull biofouling and subsequent colonisation.

Christmas Island's close geographical proximity to the Indonesian archipelago coupled with Australian sovereignty provides a "melting pot" for species from both regions to co-mingle. Several of the RAN vessels returning from Christmas Island to FBW showed a mixture of both temperate and tropical species originating from both regions. Considering the difference in biophysical conditions between Christmas Island and FBW it is unlikely to expect species translocated from Christmas Island to colonised FBW under normal conditions.

The MEAO is a relatively new region visited by RAN, and also geographically the most distant of all the regions in this survey. Three decapods and one barnacle species all low risk, were translocated from the MEAO back to Australian waters. The long voyage is likely to have caused high mortality for most species except for the most resilient, greatly reducing the number of NIMS ultimately translocated back to Australia. For this reason, this region is unlikely to pose a high threat to the biosecurity of Australia.

The RAN has a long association with the Pacific region which includes our closest neighbour New Zealand. NIMS from the Pacific Region pose little biosecurity threat to Australian waters. In this survey, no native species from this region were recorded on returning RAN vessels however translocation of NIMS from other regions which have established in the Pacific region were recorded on returning vessels.

The greatest biosecurity threat from overseas regions identified in this survey is from SE Asia, followed by the MEAO, Christmas Island and the Pacific region. Importantly, RAN vessels returning from high risk areas such as SE Asia are subject to self-regulated frequent inspections upon berthing and if required, stringent cleaning regimes. These procedures have been implemented to help mitigate biosecurity threats from "high-risk" areas.

5.5 Translocation around Australia

Identifying domestic range expansions around the Australian coastline is an ongoing problem, not just for this survey on RAN vessels but also recreational and commercial vessels. The largest number of NIMS were identified on domestic-voyage RAN vessels (*Figure 2*), predominately Trinity Inlet vessels, indicating the possibility of several species having increased their range around the northern Australia coastline. In domestic cases it is difficult to identify the point of infestation, as monitoring for the presence of NIMS on hull biofouling is less strictly regulated on national vessels compared to international vessels.

RAN vessels, as well as recreational and, to a lesser extent commercial vessels, from the same area are exposed to infestation from NIMS that can then be translocated around the Australian coastline. It is difficult to identify the initial site or vessel responsible for the infestation as vessels travelling through this region are exposed to whichever NIMS are present, allowing infestation of hull biofouling to occur. This results in vessels unknowingly spreading NIMS to other areas along the northern Australian coastline. This applies to all vessels in this area, with not just RAN vessels exposed to this biosecurity threat. Susceptibility, for both defence and domestic vessels would depend on the type of vessel, its operational profile, time spent in port and its cleaning regime.

5.6 Defence-Restricted Ports

Defence-only restricted ports such HMAS *Stirling*, Garden Island; HMAS *Kuttabul* Botany Bay; HMAS *Leeuwin* Fremantle; and HMAS *Cairns* Trinity Inlet may be subject to different invasion pressures and susceptibility to NIMS in comparison to commercial or recreational ports. In the case of the defence ports, HMAS *Kuttabul*, HMAS *Leeuwin* and HMAS *Cairns* access to the site is restricted to defence vessels, however geographically they are connected to the local port area and geo-physically they are subject to the same invasion pressures from NIMS as the surrounding ports. In contrast, HMAS *Stirling* situated on Garden Island is geographically isolated from the mainland, by Cockburn Sound and for this reason is unique compared to the other three ports. Also unique to HMAS *Stirling* is the large increase in numbers of *C. californica* unprecedented in other ports both defence and non-defence. The assumption is that the operational and procedural requirements of RAN vessels and geographic isolation of HMAS *Stirling* have predisposed this port to infestation by certain NIMS. No reason for this infestation can be attributed to RAN vessels at this time and further research is required to determine the cause of the large numbers observed. This port now serves as an inoculation point and consideration of the translocation of *C. californica* on RAN vessels from this port when travelling to environmentally sensitive or fragile eco-systems is required (Ashton et al., 2006).

5.7 Reverse Translocation

"Reverse-translocation" involving local or native Australian species translocated internationally in RAN hull biofouling pose a biosecurity risk as NIMS overseas. One example in this survey showed an Australian species (crab) capable of surviving a round-trip translocation in hull biofouling to an overseas destination. While this is an environmental issue, this also poses a reputational consideration for the RAN. This issue needs to be considered when visiting environmentally sensitive regions overseas.

6. Recommendations

1. When returning from long trans-oceanic voyages, it is good practice to use high speeds, where possible, to help slough off any susceptible hull biofouling species such as algae, sponges, ascidians or bryozoan. Also, if possible, crossing several different temperature and salinity gradients creates a less hospitable environment for NIMS and increases species mortality prior to returning to Australia.

2. Several tropical species identified in this survey were able to survive in temperate ports in biofouling on vessel hulls. Vessels returning directly to temperate ports in Australia from tropical regions would benefit from a hull inspection and cleaning, prior to any deployment to tropical climes such as the northern coastline of Australia. This reduces the number of tropical species translocated to target areas, where activation can occur.

3. The greatest biosecurity risk to Australia from international regions assessed in this survey was from SE Asia, followed by the MEAO, Christmas Island, and the Pacific region. The RAN is aware of the increased threat of NIMS from SE Asia and has instigated strict controls with continuing vigilance including isolation of suspect or

high risk vessels prior to in-water hull inspections upon docking to help control and limit the spread of invasive species from this region.

4. The largest number of NIMS identified on RAN vessels was recorded on domestic and domestic-travel RAN vessels. One explanation is that mitigation strategies are more difficult to implement domestically due to unrestricted and unregulated national travel. However, once NIMS have been identified in areas local to defence ports, RAN vessels departing from this area should be inspected and cleared prior to visiting regions free from these NIMS. This is especially relevant for protected or environmentally sensitive areas. This type of biosecurity risk is not unique to RAN vessels and similar regulations for domestic commercial and recreational vessels would also help reduce translocation of NIMS domestically.

5. The defence-restricted ports assessed in this survey were HMAS *Cairns*, HMAS *Kuttabul*, HMAS *Leeuwin* and HMAS *Stirling*. The first three ports are contiguous to the rest of the coastline with commercial and recreational vessels in close proximity to the defence port. Any NIMS present in these ports have no physical barrier to limit their expansion so it is difficult to determine the source of infestation with a variety of different vessels both defence and non-defence likely to be implicated. HMAS *Stirling* is situated on Garden Island, separated from the mainland by Cockburn Sound, and is unique in its geographical isolation from the mainland compared to the other three ports. HMAS *Stirling* is now infested with *C. californica*, not previously known to this area, and serves as an inoculation point for this species. RAN vessels berthing here need to be aware of the risk they may pose to other regions where this species is not recorded, and if necessary may require cleaning prior to departure to bio-sensitive areas.

6. Reverse translocation of Australian species is not uncommon and occurred in this survey. Pre-deployment cleaning of vessels should minimise any biosecurity risk posed by Australian species in hull biofouling on RAN vessels when visiting environmentally sensitive areas overseas.

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Appendix A. CCIMPE Trigger List

Scientific Name	Common Name
Species still exotic to Australia	
1. *Eriocheir spp.*	Chinese mitten crab
2. *Hemigrapsus sanguineus*	Japanese/Asian shore crab
3. *Crepidula fornicata*	American slipper limpet
4. *Mytilopsis sallei*	Black stripped mussel
5. *Perna viridis*	Asian green mussel
6. *Perna perna*	Brown mussel
7. *Corbula (Potamocorbula) amurensis*	Asian clam/brackish-water corbula
8. *Rapana venosa (syn Rapana thomasiana)*	Rapa whelk
9. *Mnemiopsis leidyi*	Comb jelly
10. *Caulerpa taxifolia (exotic strains only)*	Green macroalgae
11. *Didemnum spp. (exotic invasive strains)*	Colonial sea squirt
12. *Sargassum muticum*	Asian seaweed
13. *Neogobius melanostomus*	Round goby
14. *Marenzelleria spp.*	Red gilled mudworm
15. *Balanus improvisus*	Barnacle
16. *Siganus rivulatus*	Marbled spinefoot/rabbit fish
17. *Mya arenaria*	Soft shell clam
18. *Ensis directus*	Jack-knife clam
19. *Hemigrapsus takanoi/penicillatus*	Pacific crab
20. *Charybdis japonica*	Lady crab
Species established in Australia but not widespread	
21. *Asterias amurensis*	Northern pacific seastar
22. *Carcinus maenas*	European green crab
23. *Varicorbula gibba*	European clam
24. *Musculista senhousia*	Asian bag mussel/Asian date mussel
25. *Sabella spallanzanii*	European fan worm
26. *Undaria pinnatifida*	Japanese seaweed
27. *Codium fragile spp. fragile*	Green macroalga
28. *Grateloupia turuturu*	Red macroalga
29. *Maoricolpus roseus*	New Zealand screwshell
Holoplankton alert species	
30. *Pfiesteria piscicida*	Toxic dinoflagellate
31. *Pseudo-nitzschia seriata*	Pennate diatom
32. *Dinophysis norvegica*	Toxic dinoflagellate
33. *Alexandrium monilatum*	Toxic dinoflagellate
34. *Chaetoceros concavicornis*	Centric diatom
35. *Chaetoceros convolutus*	Centric diatom

Note: Endorsed by National Introduced Marine Pest Coordinating Group (NIMPCG) in 2006.

Appendix B. Monitoring target species list (D.o.F, 2010)

	Species Name	Common Name
1.	*Acartia tonsa*	Calanoid copepod
2.	*Alexandrium catenella*	Toxic dinoflagellate
3.	*Alexandrium minutum*	Toxic dinoflagellate
4.	*Alexandrium monilatum*	Toxic dinoflagellate
5.	*Alexandrium tamarense*	Toxic dinoflagellate
6.	*Asterias amurensis* *	Northern Pacific seastar
7.	*Balanus eburneus*	Ivory barnacle
8.	*Balanus improvisus* **(marine/estuarine incursions only)**	Bay barnacle
9.	*Beroe ovata*	Comb jelly
10.	*Blackfordia virginica*	Black Sea jelly
11.	*Bonnemaisonia hamifera*	Red macroalga
12.	*Callinectes sapidus*	Blue crab
13.	*Carcinus maenas* *	European shore crab
14.	*Caulerpa racemosa* **(possibly an Australian native)**	Green macroalga
15.	*Caulerpa taxifolia* **(exotic strains only)**	Green macroalga
16.	*Chaetoceros concavicornis*	Centric diatom
17.	*Chaetoceros convolutus*	Centric diatom
18.	*Charybdis japonica* * **barcoded**	Asian paddle/lady crab
19.	*Codium fragile spp. fragile1*	Green macroalga
20.	*Corbula (Potamocorbula) amurensis*	Brackish-water/Asian clam
21.	*Crassostrea gigas* *	Pacific oyster
22.	*Crepidula fornicata*	American slipper limpet
23.	*Didemnum spp.* **(exotic invasive species only)**	Tunicate – sea squirt
24.	*Dinophysis norvegica*	Toxic dinoflagellate
25.	*Ensis directus*	Jack-knife clam
26.	*Eriocheir spp.*	Mitten crabs
27.	*Grateloupia turuturu*	Red macroalga
28.	*Gymnodinium catenatum* *	Toxic dinoflagellate
29.	*Hemigrapsus sanguineus*	Japanese shore crab
30.	*Hemigrapsus takanoi / penicillatus*	Pacific crab
31.	*Hydroides dianthus*	Tube worm
32.	*Limnoperna fortunei*	Golden mussel
33.	*Marenzelleria spp.***(invasive, marine/estuarine incursions***)*	Red-gilled mud worm
34.	*Mnemiopsis leidyi*	Comb jelly
35.	*Musculista senhousia* *	Asian bag/date mussel
36.	*Mya arenaria*	Soft shell clam
37.	*Mytilopsis sallei*	Black-striped mussel
38.	*Neogobius melanostomus (marine/estuarine incursions only)*	Round goby
39.	*Perna perna*	South African brown mussel
40.	*Perna viridis* *	Asian green mussel
41.	*Pfiesteria piscicida* *	Dinoflagellate
42.	*Pseudodiaptomus marinus*	Asian copepod
43.	*Pseudo-nitzschia seriata*	Pennate diatom
44.	*Rapana venosa*	Asian/veined rapa whelk
45.	*Rhithropanopeus harrisii*	Harris mud crab
46.	*Sabella spallanzanii* *	European/Mediterranean fan worm
47.	*Sargassum muticum*	Asian seaweed
48.	*Siganus luridus*	Dusky spinefoot
49.	*Siganus rivulatus*	Marbled spine foot/rabbit fish
50.	*Tortanus dextrilobatus*	Asian copepod
51.	*Tridentiger bifasciatus*	Shimofuri goby
52.	*Tridentiger barbatus*	Shokohazi goby
53.	*Undaria pinnatifida* *	Japanese seaweed
54.	*Varicorbula (Corbula) gibba* *	European clam
55.	*Womersleyella setacea*	Red Seaweed

List of Target Species Based on Invasion and Impact Potential.
* species with a genetic/molecular probe or barcoded (DAFF, 2010).

Appendix C. Species List of NIMS from Hull Biofouling Survey

Group	Species Name	References
Serpulid	*Branchiomma cf. bairdi*	Tovar-Hernandez et al. 2008
	Parasabella aulaconota	Tovar-Hernandez et al. 2010
	Paralentia annamita	Barnich et al. 2004
(tubeworm)	*Spirobranchus minutus*	ten Hove et al. 2009
Hydroid	*Clytia hummelincki*	Gravili et al. 2008, Cornelius 1982
Cirripedia (barnacles)	*Amphibalanus zhujiangenis*	Chan 2011
	Megabalanus ajax	Jones 2003, 2004
	Megabalanus coccopoma	Henry et al. 1986
	Megabalanus occator	Harry et al. 1986, Sliwa et al. 2005
	Megabalanus rosa	Jones 2003, 2004
Caprellids	*Caprella californica*	Ashton 2001
	Paracaprella pusilla	Bhave et al. 2009
	Triperopus mirus	Arimoto 1976
Mysid	*Heteromysis brucei*	Tattersall 1967
Decapod	*Metopograpsus latifrons*	Morgan 1990, Tan et al. 1994
	Metopograpsus messor	Hartnoll 1975, Morgan 1990
	Pachygrapsus propinquus	Ng et al. 2008, Sahoo et al. 2008
	Pilumnus sp.	Ng 2002, Hewitt 2004
Molluscs (bivalve)	*Cancellaria sp.*	Garrad 1975

Subset of species identified from the RAN hull survey which are known to be invasive or problematic overseas.

Appendix D: Taxonomic Experts

Field	Name	Organisation	Position
Algae	John Lewis	ES Link	Principal Marine Consultant
Amphipoda	Dr Gary Poore	Museum of Victoria	Postdoctoral Fellow of Marine Invertebrates
Amphipoda Mysidae	Dr. Genefor Walker Smith	Museum of Victoria	Postdoctoral Fellow Marine Invertebrates
Bryozoa	Dr. Phillip Bock	Deakin University	Professor of Marine Invertebrates
Crustacea	Dr. Shane Ahyong	Australian Museum	Marine invertebrates Research Scientist
Echinodermata	Dr. Tim O'Hara	Museum of Victoria	Postdoctoral Fellow of Marine Invertebrates
Mollusca	Dr. Richard Willan	MAGNT	Senior curator, Molluscs Editor, Academic Pubs
Polychaeta	Dr. Robin Wilson	Museum of Victoria	Postdoctoral Fellow of Marine Invertebrates
Polychaeta	Dr. Maria Capa	Australian Museum	Postdoctoral Fellow Marine Invertebrates
Polychaeta	Dr. Harry ten Hove	Zoologische Museum Amsterdam	Postdoctoral Fellow of Marine Invertebrates

Taxonomy experts that contributed to the identification of marine biota collected from the RAN hull survey.

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19. ABSTRACT

The translocation of marine species by anthropogenic vectors, such as ships' ballast water, hull fouling, and fouling in sea chests and internal seawater systems, poses a biosecurity issue by enabling the colonisation and establishment of species in regions beyond their native range. To gain understanding of the biosecurity risk posed by biofouling from RAN vessels returning from overseas DST Group conducted a survey of hull biofouling, with URS Australasia sampling 26 RAN vessels, which involved 53 inspections over the period 2001 – 2010, including at least one representative from all commissioned classes. Also, DST Group conducted port surveys of four defence-restricted ports where RAN vessels from this survey were berthed to determine if there was any increased threat due to differences in the RAN operational aspects compared to non-defence vessels. Similarly, the regions visited by RAN vessels in this survey were assessed to determine which region posed the highest biosecurity threat to Australian waters. The hull biofouling survey identified over 260 different taxa of macroalgae and macroinvertebrates and vertebrates. Twenty-one of the taxa identified have been previously reported as invasive marine pests overseas and are therefore considered potentially invasive in Australian waters. This subset of twenty-one species will be looked at in depth in this report to determine the potential biosecurity threat they pose to Australia

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